Effect of global warming on the distribution of parasitic and other infectious diseases: a review

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Introduction

Assuming current trends continue, significant global warming via the 'greenhouse effect' seems inevitable; disequilibrium in physical and biological ecosystems will ensue, and the faster the changes occur the less likely it is that human (and other) societies will be able to adapt without serious resultant consequences[1-4]. Natural climatic changes in the past have occurred over thousands or millions of years; global warming of 5000 to 15 000 years ago completely changed the face of the planet[5,6]; this was, however, insidious unlike the rapid change which man-made 'global-warming' will precipitate. Present predictions on extent and geographical distribution of climatic change are based on incomplete scientific projections coupled with a significant quota of crystal-ball gazing!

The potential impact of climatic change on communicable disease patterns can be summarized[3]: (i) modification of vector (usually arthropod) ecology - this relates principally to infections currently prevalent in tropical and subtropical regions, (ii) intensification of human-related risk factors - including reduced availability and quality of drinking water, cooking and sanitation facilities, extent of irrigation, etc, and (iii) an increase in soil, airborne and other diseases, directly related to the socioeconomic consequences of changed human behaviour.

Change in the distribution of parasitic diseases

Vector-borne infections

These are dependent on parasite survival, and ultimately geographical distribution of the vector; an increase in prevalence of insect-borne disease therefore seems inevitable[1,4,7]. Insect vectors of many diseases (together with the pathogens they transmit) are temperature-sensitive[8]; the extrinsic incubation period of the four human species of *Plasmodium* varies inversely with ambient temperature[9]. Vector-borne diseases are unusual, or rare, in cold climates. The occurrence of vector-borne disease is determined by[3]:

(i) abundance of the vector, and intermediate and reservoir host(s),
(ii) prevalence of disease-causing parasites (and other pathogens, viruses included) suitably adapted to those vectors, the human (or animal) host, and local environmental conditions (especially temperature and humidity), and
(iii) the resilience and behaviour of the human population, which is in dynamic equilibrium with vector-borne parasites and pathogens.

Table 1 summarizes the world's major vector-borne infections.

Until relatively recently *Plasmodium* sp infection was widely distributed in Europe (southern parts of

Table 1. Global status of some major vector-borne diseases[3]

Disease	Populations at risk (millions)*	Prevalence of infection (millions)	Present distribution	Likely change of distribution as a result of climatic change
Parasitic diseases				
Malaria	2100	270	tropics/subtropics	+++
Filariasis - lymphatic	900	90.2	tropics/subtropics	+
- onchocerciasis	90	17.8	Africa/L America	+
- dracunculiasis	63	1	tropics (Africa/Asia)	o
Leishmaniases	350	12 million infected+ 400 000 new cases/year	Asia/S Europe/Africa S America	?
African trypanosomiasis	50	(25 000 new cases/year)	tropical Africa	+
Schistosomiasis	600	200	tropics/subtropics	++
Arboviral diseases				
Dengue	No estimates available		tropics/subtropics	++
Yellow fever			Africa/L America	+
Japanese encephalitis			E/SE Asia	+
Other arboviral diseases				+

*Based on a world population of 4.8 billion (1989)
o, unlikely; +, likely; ++, very likely; +++, almost certain; ?, not known

Table 2. Environmental factors determining the survival of vectors of disease-causing agents[3]

Abiotic:	temperature precipitation relative humidity wind solar radiation topography fresh water ponds, rivers, lakes
Biotic:	vegetation hosts (mammals, reptiles, birds) natural predators, parasites, pathogens of the vector

the continent remained affected until the 1950s)[10], and north America[3]; the reason(s) for its withdrawal in a southerly direction is not entirely clear, but improvement in underlying socioeconomic conditions (including drainage of marshy ground) was certainly important. A higher ambient temperature would favour the return of *Plasmodium* sp-carrying anopheline mosquitoes.

Vectors require a complicated ecosystem for their survival and reproduction (Table 2)[3]. An increase in both temperature and rainfall would expand habitats favourable to malaria vectors[3]; alternatively, increased temperature, coupled with reduced rainfall would favour new habitats for *Phlebotomus* sp - the vector(s) for the leishmaniases. Decreased ambient humidity would encourage lymphatic filarial transmission. Transmission which is at present seasonal might (due to an effect on vector reproduction and longevity) become perennial, and vice versa[3]. Furthermore, changes in vectorial capacity might occur; rate of development of the parasite/pathogen within the vector is temperature-dependent. High altitude sites and others in northerly latitudes, eg the presently malaria-free highlands of Ethiopia, Indonesia, and Kenya[3], might become hospitable to certain vectors.

Nearly 40 mosquito species of the genus *Anopheles* can act as vectors for human *Plasmodium* sp[3,11]; the distribution of each is restricted by environmental factors, and many have a far greater distribution than the disease. Climate (especially ambient temperature) directly influences mosquito development, the gonotrophic cycle (rate and success of maturation are determined by ambient temperature), longevity, and duration of extrinsic development of *Plasmodium* sp; furthermore, it affects other environmental factors, eg vegetation and breeding sites. In malaria-endemic areas, acquired host-immunity is partly lost during the non-transmission season giving rise to a dramatic increase in cases during the remainder of the year[3]. Lengthening or shortening of the vector-breeding season (via climatic change) would affect the prevalence of malaria. In some parts of India, *Anopheles culicifacies* is the vector for *Plasmodium* sp[3]; this species breeds in river beds; onset of the monsoon significantly affects the availability of breeding habitat, size of vector population, and disease transmission. When once established, eradication could become extremely difficult[9]; vector control (in a world context) has failed, and the likelihood of a safe and effective vaccine is currently receding[12].

An increase of mean ambient temperature in central Africa by 2°C, would result in the tsetse fly - which transmits *Trypanosoma brucei* sp infection to man - disappearing from the middle belt of Africa (where it is presently endemic) southwards[13]. The tsetse fly would breed more efficiently in the forest belt where rainfall would be greater[3]; furthermore, climatic change would significantly affect the development of the parasite within the vector. These events could prove disastrous for human populations, but perhaps more importantly (in the case of trypanosomiasis) for domestic animals in infected areas. Other examples of vector-borne parasitoses which might increase include[2,3]: filariasis and leishmaniasis. Global warming would extend areas populated by the mosquito-vector(s) of the lymphatic filariases; however, resultant socioeconomic factors are likely to be more important as disease-determinants worldwide[3]. The specific vector (*Simulium* sp) for onchocerciasis is *not* at present invading certain areas which are climatically suitable[3]; therefore, although minor shifts in this disease might result from climatic change, major ones seem unlikely.

Agricultural practices will alter as rainfall patterns change[3]; irrigation, cropping patterns, livestock husbandry and fertilizer/pesticide application will also change. Changes in irrigation practices will inevitably affect the world distribution of malaria, schistosomiasis (and Japanese encephalitis), but the precise nature of these will be exceedingly complex[3]. A projected rise in sea-level (with subsequent coastal flooding) will affect vector breeding in many tropical locations; changes in fast-running river beds will affect the breeding of *Simulium* sp. Drought and desertification will have a beneficial effect on certain vector-borne diseases: (i) vector breeding is generally linked to an aquatic environment, and (ii) vector longevity is frequently related to relative humidity, dracunculiasis and leishmaniasis being exceptions[3]. Drought and hydrological changes affect natural vegetation cover, and have a resultant impact on a wide range of vectors, eg those responsible for African trypanosomiasis, Chagas' disease [several arbovirus diseases, and certain viral, rickettsial and bacterial infections (of man and animals)] - including the leishmaniases[3].

[The nematode *Haemonchus contortus* is economically important in sheep[13]; although survival time decreases at high temperature, development increases rapidly and it remains infective over a wide temperature range; as a result, it is likely to increase in distribution - at a time when drug-resistance is rapidly spreading.]

Schistosoma sp which is responsible for the water-borne parasitosis, schistosomiasis (bilharzia) - has clear climatic preferences; warming of expanses of freshwater (containing various species of freshwater snail) could predispose to a marked increase of infection in endemic areas, and in some temperate ones also. In Egypt, snails tend to lose their infections during the cooler winter months (and vice versa)[14]. These trematodes - which reproduce rapidly - are capable of adapting to a new environment with great speed[2]. Therefore, a more favourable climate would expand the areas at risk[3]. Prevalence of schistosomiasis is also closely linked to irrigation agriculture; therefore, a spread of rice cultivation would probably lead to a further increase in prevalence.

One author has summed up the situation thus: 'changing climate will spell boom days for parasites . . .'; he has also concluded: 'Parasites are good at solving problems, and because they reproduce so quickly, they always win'[13].

Non vector-borne parasitoses
The soil-transmitted nematodes (eg, hookworm and *Strongyloides stercoralis*) are examples of parasites which do not require a vector for transmission[2]. [*Ascaris lumbricoides* and *Trichuris trichiura* possess a relatively heat- and drought-resistant egg stage; hence their prevalence is unlikely to be influenced greatly by climatic change.] Survival of eggs and larvae in moist soil is temperature dependent. Therefore these, and several other soil-transmitted helminths, are likely to increase. Also, the situation would rapidly worsen in the presence of a decline in sanitation and public health standards - resultant upon 'global warming' (see below).

Non-parasitic vector-borne infectious diseases

Many viral infections require a vector for transmission[14]. Examples are: dengue (the vector is more widely spread than the present distribution of the disease), yellow fever, viral encephalitis[15], Congo-Crimean haemorrhagic fever, and rabies[2]. In many instances, both insect-vector and pathogen are sensitive to temperature[7]; for example, the incubation period of yellow fever - previously endemic in the temperate zone (epidemics occurred in Portugal, Spain and the USA)[16,17] - varies inversely with temperature[12]. Hantaan virus disease - conveyed by rodents - already exists in central and Eastern Europe and could assume a major significance.

The vectors of arboviral diseases breed in a wide range of climates[3]; when temperature and humidity rise, they will probably invade areas not presently infected. *Aedes albopictus* (a vector for dengue and dengue haemorrhagic fever in south-east Asia) has, for example, already established itself in the USA[3]. Dengue, and other encephalitides caused by arboviruses, including yellow fever, and Rift Valley fever are considered potential risks to the USA in the event of significant climatic change[14]. An increase in temperature shortens the reproductive cycle and extrinsic developmental period of some pathogens; this allows the transmission of several diseases, eg St Louis encephalitis, Japanese encephalitis, dengue, and Rift Valley fever. Under favourable conditions, arbovirus infections can change from being endemic to epidemic. In Australia, global warming could increase mosquito-borne diseases, eg Australian encephalitis and Ross River virus infection (epidemic polyarthritis)[18]. In the USA, Rocky Mountain spotted fever and Lyme disease (caused by *Borrelia burgdorferi*) might spread northwards[14,19].

Infections related to poor sanitation

Many non-vector-borne diseases are related either directly or indirectly, to the quality and quantity of the water supply. In developing countries, global warming will inevitably expand areas where sanitation is substandard; water would become a scarce commodity[4]. *Escherichia coli*, *Vibrio cholerae*, *Salmonella* sp, hepatitis A and E (HAV and HEV), poliomyelitis, *Giardia lamblia* and *Entamoeba histolytica* are organisms directly transmitted by infected water, or contaminated food infected by water[3]. Insufficient water-availability also favours transmission (due to inadequate hand-washing and personal hygiene). Prevalence of *Shigella* sp, *A. lumbricoides*, *Trichuris trichiura*, and *Enterobius vermicularis* is also likely to increase[3]. Cholera, typhoid, plague, and typhus are examples of bacterial and rickettsial diseases which might become epidemic; cholera, plague and typhus previously existed in the temperate zone[14].

Depression of human immunity by ultraviolet radiation

Immunity to many infectious diseases is mediated via a cellular response; this will diminish as ultraviolet (UV)-B radiation intensifies[1-3]. Exposure to summer sunlight is known to increase T-suppressor and decrease T-helper cell concentrations in peripheral blood[2]. This will influence the development and course of many infective diseases. Mild infections in the immunosuppressed individual could become lethal[2]. This is likely to apply to tuberculosis, leprosy and HIV infections; an additive effect on HIV-infection and associated 'opportunistic' events could be catastrophic. Studies are urgently required to evaluate further the effect of UV-B radiation on human humoral immune function, development of infectious diseases (and autoimmune reactions), and efficacy of vaccination strategies[3]. In countries where sanitation is unsatisfactory, water supplies are contaminated, and health care systems inadequate; a significant increase in infectious diseases will result. Non-immunized individuals in developed countries might also suffer greater morbidity from some infections.

Global warming and nutritional status

Following a major disruption within the ecosystem, malnutrition could assume major importance. This would result largely from an increase in the frequency and severity of infections (see above).

In developing countries, especially Africa, the effect of environmental change on agriculture and food supplies might be of greater importance than the increase in human infection. [Current speculation suggests that recent droughts in northern Africa reflect the beginning of the 'greenhouse effect'[20].] The result would be increasing droughts, a resultant decrease in crop yield[14], an increase in 'pests', loss of fertile land (as ocean-levels rise)[1,14,21], and increased soil salinity and erosion; the ultimate result will be a decrease in surface area of arable land[1,2]. An increase in UV-B radiation (and air pollution) also impairs photosynthesis; oceanic food production will be reduced by an effect of UV-B radiation on nitrogen-fixation in phytoplankton, and sea-water warming[2].

Increased malnutrition in developing countries will also predispose to an increase in tuberculosis and leprosy in non-immunized individuals, together with other nutrition-associated diseases - including measles, pertussis, and poliomyelitis.

Other factors responsible for changing patterns of infectious diseases

Respiratory irritants - including chlorofluorocarbons and other toxic emissions[3] are likely to pollute the atmosphere to a greater extent[1,2]. The degree of transmission of airborne infections will change as ambient temperature increases[22]. An increase in pulmonary infection(s) seems likely; morbidity and mortality from chronic bronchitis, bronchiectasis, bronchial asthma, and obstructive airways disease will escalate[14]. Pneumonia is already an important cause of morbidity and mortality in developing countries; both climate and seasonality seem important, but the overall effect(s) of climatic change are difficult to forecast[3]. A secondary effect of pulmonary disease would result in increased cardiac morbidity and mortality via cor pulmonale[2]. Influenza is characterized by pandemic waves; these tend to be seasonal, rather than temperature related. As nations strive for higher living standards, industrialization will continue to increase - with more atmospheric pollution.

In Africa - especially in the semi-arid region south of the Sahara - meningitis epidemics tend to correlate with change from wet to dry seasons[3]; droughts might extend the areas involved.

Overcrowding, undernutrition (see above), poor access to health care, disturbed social conditions, and rapid uncontrolled urbanization - precipitated by climatic change - might increase[3]: tuberculosis, leprosy, skin infections, measles and other childhood infections, ectoparasitic infections, and probably plague.

Possible advantage of global warming on an 'infective' disease

Multiple sclerosis might be a manifestation of an aberrant immune response to a viral infection. Epidemiological evidence indicates that the disease is unusual in warm climates, becoming more common at northerly and southerly latitudes[23]. In the event of global warming this debilitating disease could theoretically diminish[4].

Conclusions

The impact of man-made global changes on the world's ecosystem(s) are likely to be more rapid, complicated and severe than any which have previously affected *Homo sapiens*[13]; the impact on distribution of infectious disease, especially the parasitoses, will be vast.

Many environmental changes will depend on local topography; assessment(s) of the risk-level should be studied in areas currently free of vector-borne disease, bordering on endemic areas. The impact of climatic change on vector behaviour in areas where there is perennial or seasonal transmission should be closely monitored[3].

Vector control has been relatively inadequate in recent years; lack of resources, and insecticide-resistance are largely responsible[3]; malaria and dengue have consequently increased in prevalence. Control measures might become even less effective due to behaviourial changes induced in the vector. Vector control measures must be critically evaluated therefore, from both national and international viewpoints[3].

Predictions of effect(s) of climatic change on agricultural practice(s) are available; their implications for vector-borne disease should be assessed[3].

The following measures should be implemented as a matter of urgency[5]: health education on an international scale[11], clean and more efficient energy supplies, reduction in carbon dioxide and other greenhouse emissions[5], maintenance of species diversity[24], preservation of rain forests (destruction will imperil thousands of species)[25], abandonment of non-biodegradable materials, strict regulation of toxic pollution, and widespread sustainable agriculture practice. Underlying the problem is human overpopulation (mostly in the poorest countries[14]) of the world[2,11]; this will have escalated 5-fold between 1850 and 2000. The time has arrived when every responsible citizen, including those exerting major influences on religious policies, should advocate effective worldwide contraception.

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